FIRE-TUBE

V.

WATER-TUBE BOILERS

BY

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CONSULTING ENGINEER

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General.

There is a belief among a certain class of persons, through thoughtlessness, lack of sufficient information or ignorance of fundamental principles, that water-tube boilers are more desirable than fire-tube boilers. Young engineers appear to hold this belief to a greater extent than the older, and many of them, without doubt, feel that they are not up-to-date if they advocate fire-tube boilers, and it is chiefly for this reason that water-tube boilers are widely used in electric power stations. It is the purpose of this paper to show that the claims made for water-tube boilers are not justified by facts, and to give reasons in detail, and not assumptions, why this is so. Water-tube boilers are purchased with various objects in view, scarcely one of which is ever realized, and it will be very unfortunate if boiler users do not come to a full realization of the advantages of fire-tube boilers.

Types of Boilers.

Among fire-tube boilers there are only two types that need, in general, be considered, viz., horizontal return tubular and vertical. Among water-tube boilers there are both horizontal and vertical, and some that are a combination of both. Some have straight tubes that enter so-called headers, or stay-bolted water legs that communicate with drums above and below, and some have bent tubes entering the drums directly. Much ingenuity has been shown in the design of water-tube boilers for the purpose of accomplishing some supposed advantage.

Object of Water-tube Boilers.

Water-tube boilers were originally designed to promote safety. This was at a time when there were numerous explosions of fire-tube boilers, and when the reason for such explosions was not known. It is now known that fire-tube

boilers have exploded because lap joints were used for the longitudinal seams. Since these boilers have been built with butt joints having double covering plates there has not been a single explosion of either horizontal or vertical boilers except one of the latter, which had a feature which would not meet with general approval.

The idea of containing water and steam under pressure in small tubes instead of large shells is attractive, but in carrying it out the small tubes have become only a part of the device, and large and small shells and flat, staybolted surfaces are used. The water-tube boiler, then, has become a complicated device with bad forms, is water tube only in name, and is about half water-tube and half shell or staybolted boiler. The absurdity of some of the designs is so evident on scientific examination that it is strange that the selling ability of the makers is sufficient to make a success of the business. The designers seem to be satisfied if they devise a boiler with some water tubes and the remainder of almost anything else.

The best forms of water-tube boilers are those having tubes expanded into the sides of drums, as they come nearest to carrying out in the best way the water-tube idea. They, however, necessarily make an unbalanced structure of the drums, of which there are from two to four, or even more, and cause the drums to change their form under pressure and bend back and forth along the weakest lines. Such drums are as likely to explode as the old lap-joint fire-tube boiler, and for the same reason.

Rapid Steaming and Responsive Qualities.

The claim that water-tube boilers are more rapid steamers and more readily respond to sudden demands than fire-tube boilers is one oftener made than any other. This is asserted on the assumption that they contain less weight of water in proportion to the heating surface than fire-tube boilers. This is an incorrect assumption, as can be easily shown. The following figures refer to the three most conspicuous kinds of water-tube boilers, and others as named, of certain sizes that the writer has examined, and gives the weight of water contained in each kind per square foot of heating surface: —

Water-tube boiler A,	7.66	lbs. per sq. ft. of heating surface.
" " B,	8.34	" " " " " " "
" " C,	8.62	" " " " " " "
" " D,	8.37	" " " " " " "
Vertical water-tube boiler,	10.30	" " " " " " "
90″ horizontal tubular,	7.74	" " " " " " "

84″	horizontal	tubular,	7.24	lbs.	per	sq.	ft.	of	heating	surface.
78″	"	"	7.00	"	"	"	"	"	"	"
72″	"	"	6.73	"	"	"	"	"	"	"
Manning	vertical,		10.3	"	"	"	"	water	"	"
"	"		7.14	"	"	"	"	total	"	"
Corliss	"		15.60	"	"	"	"	water	"	"
"	"		11.00	"	"	"	"	total	"	"
Dean	"		12.00	"	"	"	"	water	"	"
"	"		9.30	"	"	"	"	total	"	"

These figures show that the claim for water-tube boilers is not substantiated. One maker of water-tube boilers, finding that his boiler contains a great deal of water, states that it is very advantageous because when the steam pressure falls the water will liberate steam and tend to keep the pressure uniform. The absurdity of this claim is apparent if we consider, for example, that in the case of a boiler holding 16,000 pounds of water at the temperature corresponding to 125 pounds of steam, if the pressure should suddenly drop to 120 pounds only 56 pounds of new steam would appear at the last-named pressure. That would last a 250-horsepower compound engine one minute.

It makes no difference, however, whether a boiler contains much or little water as far as sensitiveness or responsiveness is concerned, for if a boiler has its working pressure, and additional heat is applied on account of the damper opening or the fire being broken up, not a unit of this additional heat can be absorbed by the water in the boiler. The water already has its full supply of "heat of the liquid," and the additional heat produces evaporation only. If the pressure is down a few pounds the absorption of heat by the liquid while the pressure is reaching its normal is insignificant in comparison with the heat that goes to make steam. If the pressure is undulating, the liberation on reduction of pressure counterbalances the absorption on increase of pressure, both being insignificant. The smallness of these quantities can better be realized when it is remembered that the small quantity of 1 pound of coal in a good boiler will give to the steam some 10,000 units of heat, and that this will raise 10,000 pounds of water 1° F. Finally, all boilers with the same amount of heating surface and the same addition of heat are equally responsive, independent of the quantity of water they contain, if they are so designed that they absorb the heat instead of allowing it to pass up chimney.

It is often asserted that certain boilers are good steamers. All boilers are good steamers if they are liberal in size for the work to be done, especially if there is ample draft, and it is safe to assert that the type of boiler has little or nothing to do with it.

Forcing Capacity of Boilers.

The ability of water-tube boilers to stand forcing is no greater than that of fire-tube boilers. The boilers that undergo the greatest amount of forcing are those on locomotives, in comparison with which the forcing of water-tube boilers in any service is insignificant. In stationary service the fire-tube boiler will stand any amount of forcing, and instances of this are given in the table of boiler performances elsewhere in this pamphlet. (See tests Nos. 27, 28, 30, 31, 61 and 62.)

In regard to forcing, the statement that water-tube boilers can be forced beyond their rated capacity merely implies that fire-tube boilers cannot be. A moment's consideration will show that the ability to force a boiler depends upon the ability to increase the draft beyond that usually obtained, and as nearly every plant has and should have a surplus draft, the mere opening of a damper is all that is necessary to produce forcing. There are cases where boilers are equipped with grates so fine that they soon stop up with ashes and clinkers, and in these cases an increase in draft can accomplish but little. In such cases the boiler gets a bad reputation for want of capacity, when it is due solely to the grate. The writer's firm replaced an overgrown plant of tubular boilers that had narrow openings in neglected, old, warped grates that were always filled with cinders and ashes with a few water-tube boilers having an excellent open, shaking grate. The old boilers also had a great ramification of smoke flues so arranged that the chimney draft was materially reduced before it reached the obstructed grates, and the total effect was that a surplus of grate area and heating surface was frequently insufficient to make the steam required. The lesser amounts of each in the new boilers with their efficient grates and ample and direct flues proved to be a surplus. This might be by many wholly attributed to the qualities of water-tube boilers.

Let us examine this matter more closely. A boiler that has its heating surface so disposed that it is all useful ought to be the best boiler for forcing. With an open grate and plenty of draft there is no practical limit to forcing, and the more the fire is driven the more steam the boiler will make. Often the economy falls off, but this is not necessarily so. In every water-tube boiler there is considerable heating surface that is never effective because, partly, the gases never can go into the corners, and because, also, some of the surface is covered with tiles. It is claimed by the makers of water-tube boilers having longitudinal paths for gases, that the gases fill the corners better than in the case of those boilers having transverse paths for gases; that the gases embrace the whole of the tubes and render them effective; and that thereby they are able to

employ less surface per horsepower and leave ample margin for forcing. There is, possibly, some truth in this, but the longitudinal layers of tiles on the tubes that produce this effect cover so much of the surface that there is much heating surface practically lost. In any water-tube boiler the gases tend to, and do, short circuit and go more or less in straight lines from the edge of one set of tiles to the edge of the next, thus losing the effect of a good deal of heating surface. This can be plainly seen if a person will take the trouble to observe. In addition to the defects named, the tiles of water-tube boilers sometimes slip out of place or fall out entirely, and then the gases short circuit more and get to the chimney even more directly than usual. Moreover, the spaces between the tubes average large, and while it is held that the gases passing between two tubes impinge on the next tube beyond, and thereby give up more heat than they would otherwise, this is only moderately true. There is little if any virtue in this impinging, and where it takes place wedges of clinker form and cover the surface, thus diminishing its efficiency.

Now let us see what is the case with the horizontal return tubular boiler. Let us carefully consider its properties. If the smoke nozzle is as wide as it ought to be — that is to say, if its width almost equals the diameter of the boiler — the distance from the end of the fire to the beginning of the smoke flue is the same through any tube. Therefore there is no short distance by any path to cause any tube to do less than any other. Moreover, it is inconceivable that the vacuum to produce draft is not the same throughout the smoke box, and, therefore, from this condition, the effect must be to cause every tube to do its full duty. Still further, these conditions exist whether the boiler is working gently or is being forced. Finally, this boiler, for these reasons, which I believe cannot be denied, is a perfect boiler as far as effectiveness of heating surface is concerned. Can any water-tube boiler compare with it in the perfection of these conditions? When the gases pass through fire tubes the skin friction causes the gases to roll over and over from center to outside, bringing every part of them repeatedly in contact with the tube surface. Nothing can surpass this in effectiveness for causing gases to give up their heat, and in order to adapt fire-tube boilers to forcing it is only necessary to lengthen the tubes so that the rolling-over process shall be prolonged. A similar argument applies to vertical fire-tube boilers, and these have the advantage that the tubes probably keep cleaner and all sides are equally effective.

It should be expected, therefore, that they are very efficient boilers, when forced. As the most practical evidence of this, I refer to the tests Nos. 30 and 31, page 17, in the lists given, which are the results of tests of two of ten boilers of the horizontal tubular type, 90 inches in diameter, built for S. D.

Warren & Co.'s paper mills, having 258–3 in. tubes 20 feet long, and having 4,027 square feet of heating surface on the fire sides for each boiler. It will be observed that 42.2 and 37.6 pounds of coal were burned per square foot of grate per hour, and that a boiler horsepower was obtained from 6.39 and 5.43 square feet of heating surface, respectively. It will be seen that the temperature (569° and 645°) of the escaping gases is very low for such forcing, and that the economy (11.53 and 12.06 pounds per pound of combustible from and at 212°), as shown by the evaporative rates, has probably never been reached under such conditions by any other boilers. In tests Nos. 32 and 33, page 17, the same boilers were run near their rating, which was based on 10 square feet of heating surface per horsepower, and the economic results are extraordinary. Tests Nos. 61 and 62, page 18, show similar results for vertical boilers.

Tests Nos. 27 and 28, page 17, give results from a horizontal tubular boiler twenty-four years old, having the original set of tubes. They show excellent results (11.18 and 11.57 pounds per pound of combustible from and at 212°) when burning coal at a rapid rate and giving a boiler horsepower with from 8 square feet and 7.7 square feet of fire-heating surface, respectively.

Circulation.

The question of circulation is one that never requires consideration in anything but a water-tube boiler. In a fire-tube boiler the paths for circulation are short, and the spaces are numerous and effective. My experience, both in stationary and locomotive practice, is that nothing can be done to prevent circulation. I have crowded tubes into a horizontal boiler, placing them ¾ inch apart, but know of no reason to suppose that the water does not circulate properly. The Cumberland Mills 90-inch return tubular boilers, with 258–3 in. tubes ¾ inch apart, developing a horsepower with 5.43 square feet of heating surface, give less than one-half of one per cent. of moisture in the steam. The Washington Mills 10-foot boilers, with 590–2½ in. tubes ⅞ inch apart, and with no wide mid-space between the tubes, when giving a horsepower on 8.51 square feet of heating surface gave one-half of one per cent. of moisture. In both these designs nothing was done to favor circulation, and there is no evidence that it is lacking. It might even be said that everything was done to prevent circulation.

Safety.

Under a previous heading something has already been said on this subject. The tubes of water-tube boilers when coated with oil or "dirt" often explode (see page 25) because they get overheated, and loss of life is frequent. As the

late Admiral Melville said, the pressure is on the wrong side of the tubes. In fire tubes the pressure is on the outside and they cannot explode, nor do they collapse. When they corrode through they harmlessly leak. In "The Locomotive" for January, 1913, ten explosions of water-tube boilers are reported for September, 1912, and twenty for October.

There have been so many explosions of water-tube boilers that the claim for safety can no longer be made. Six views are given in this pamphlet, pages 21, 23 and 25, which show a few cases of explosions of water-tube boilers. There have been many others, but, as before stated, not one of horizontal return tubular boilers when built with butt joints, and none of vertical fire-tube boilers, with the exception already noted.

It is, from this, apparent that the water-tube feature of boilers is not in itself a source of safety. The drums of vertical water-tube boilers have been known to pull away from the tubes. Where there are separate headers for a few tubes an explosion caused by one header pulling off or rupturing would probably injure property and cause loss of life. Explosions of headers frequently occur. Moreover, the drums of water-tube boilers are as likely to explode (see page 25) as the shells of the fire-tube type, and from the same causes. They vary in size from, say, 24 to 54 inches, 36 and 42 inches being very common, and are amply large to demolish buildings as well as to kill people.

One concern, of which the writer's firm are consulting engineers, discovered that a drum plate was cracked all but off, and would have certainly exploded in a short time. This drum was made with a lap joint on the longitudinal seam, and the bending of the plate at this joint, in order to become more or less circular with variations of pressure, caused the crack.

There are some water-tube boilers that have four drums. I consider such boilers four times as dangerous as shell boilers because there are four things to explode against one. When these drums have tubes entering one side, and are expanded into a heavier plate riveted to a thin one by a lap joint, the thin plate, in time, is likely to crack at the edge of the lap and cause an explosion. Such drums having within them unbalanced pressure become elliptical with an increase of pressure, and vary their form with variations in pressure. The bending effect upon the plates is localized at the edge of the joint, and final rupture is probable.

On account of the probability of the explosions of water tubes the self-closing stop valve was devised to prevent the steam and water of other boilers in the room from discharging through an exploded tube or other part of one boiler. Such valves are not required on fire-tube boilers. An authority has

recently written: " There have been innumerable lesser explosions of water-tube boilers, and we have come to regard them as a dangerous class, notwithstanding their so-called appellation, ' safety.' "

Accessibility.

In order to enter the drums of water-tube boilers it is necessary to remove manhole covers, and there may be as many as four of them per boiler against two for the horizontal tubular. In order to examine the interior of the tubes of some designs of water-tube boilers it is necessary to remove hundreds of hand-hole plates, clean off the joint surfaces and make over the joints when replacing the plates. With some other types it is not necessary to remove hand-hole plates, but in most of them the tubes are bent and they cannot be seen through. The outsides of the tubes can be seen as well as those of fire-tube boilers in most instances. In horizontal return tubular boilers the insides of tubes can be seen by merely opening the front door, and the outsides can be seen from above and somewhat from below.

With vertical boilers as usually made internal inspection is not easy, but designs have been made with a manhole which renders the interior accessible.

Repairs.

There are so many explosions (see " The Locomotive ") of tubes, headers and drums of water-tube boilers that the cost of repairs is much greater than of fire-tube boilers. The tile baffles of water-tube boilers are very delicate when they are at right angles to the tubes, often get out of place and broken, and are troublesome to replace.

Cleaning.

The removal of soot from the fire surfaces of water-tube boilers cannot be accomplished by any ordinary means.

Blowing in among tubes that are shielding each other is very ineffective, and the more distant tubes scarcely feel the effect of the blast. Moreover, the steam jet widens and loses its force a short distance from the outlet. If anybody should be fortunate enough to see a water-tube boiler that has been in service a few years, with the brickwork removed, as I have, they would be impressed with the truth of this statement. It is sometimes said that water tubes can be scraped on the outside. It is obvious that they cannot be scraped when the boiler is hot, and it surpasses the imagination to understand how it can be well done under any circumstances. The fact is, moreover, that not one water-tube boiler in thousands is ever scraped.

Compare these conditions with those of a fire-tube boiler. Each tube can be blown with a jet of steam with the absolute certainty that the jet will strike every part of the interior and blow off everything movable, since it is confined and loses but little of its force. In addition, the tube can be scraped perfectly clean. Moreover, both blowing and scraping can all be done while the boiler is in service. A fireman who would not scrape a fire tube once a week would be discharged in most places, but for some reason or other water-tube boilers are accepted when they cannot be scraped at all, and can only be very imperfectly blown. The class of water-tube boilers that can be blown through hollow stay bolts parallel to the tubes is somewhat better in this respect, but the steam jet is not confined and is correspondingly ineffective. Besides, the soot and ashes blown from most of the tubes probably lodge on the horizontal layers of tiles and ultimately partially cover other tubes, rendering them somewhat ineffective.

The accumulating dirt on the outside of water tubes, added to the filling up of the insides, makes the efficiency gradually vanish during their service. These are defects of the greatest importance, and I am constantly surprised that they are so seldom mentioned.

The insides of the tubes of water-tube boilers accumulate incrustation, and it often becomes very thick and hard. They have to be bored out by a very slow process. The outsides of the tubes of fire-tube boilers become coated with scale to some extent, but this can be cracked off by means of a steam or air-driven multiple hammer which can be run through the tubes. The scale drops to the bottom and can be removed through the manhole. Water-tube boilers with bent tubes require a special flexible tube borer, and this is usually furnished with the boiler. Cases occur where the scale is such that the borer cannot enter the tubes.

Superheating.

Superheating by means of tubes incorporated within the boiler has now become established, rather than separately fired superheaters, and the economy of it has been fully established. Superheating to any degree can be done with horizontal return tubular boilers satisfactorily by means of Foster superheaters. With water-tube boilers it is done in a variety of ways. In vertical fire-tube boilers the steam is superheated some 20° to 30° without any special device. This can be increased still more by a greater than usual length of tubes exposed to the steam, and to any extent by adopting the method used in locomotives.

Economy.

The economy of fire-tube boilers is superior to that of water-tube boilers for several reasons.

1. The tube-heating surfaces of fire-tube boilers can be blown with a steam jet with the certainty that all parts of the surfaces will be swept by the blast and made as clean as a blast can make them. In addition, the tubes can be scraped. The bottom of the boiler is not usually cleaned, but as this is a very small part of the total heating surface it is of slight importance, and it is better that it should become dirty and thus somewhat retard the entrance of heat and protect the plate if dirt is on the inside of the shell. In water-tube boilers a jet of steam strikes some tubes and these shield the others. The steam dissipates and has almost no effect on the distant tubes. In some designs the condition in this respect is better than in others, as, for example, those in which the jet travels lengthwise of the tubes, and those having horizontal drums connected by nearly vertical tubes. In such cases the steam can dissipate vertically and horizontally, and loses its cleaning power before it reaches the ends of the tubes. The tubes near the clean-out doors are fairly clean, but those at the farther side are deeply covered with soot, caked on.

2. Much of the heating surface of water tubes is almost valueless because the tubes nearest the fire become incrusted in clinker, and in some of them tiles rest upon the other sides of the tubes, so that these tubes are all but useless as heating surface. Perhaps this covering is advisable for the protection of the tubes if they are dirty inside.

3. The brick surface of the setting of water-tube boilers is in general greater than of horizontal return tubular boilers, and as brickwork always leaks, more air enters to cool water-tube boilers than the others. In addition, the clean-out doors on the sides of water-tube boilers always leak air, and by expansion and contraction become loose. If they are again cemented they will soon work loose. In addition to this the types of water-tube boilers that have front doors never have them tightly fastened, and as they are large and have a long perimeter the air leakage is great. This all reduces economy, and analyses of escaping gases from fire-tube and water-tube boilers in the same plant will always show more free oxygen in the latter than the former. The cooler gas reduces the effect of an economizer if one is used. The vertical fire-tube boiler is free from this defect, the gas leaves at a higher and normal temperature and renders an economizer more effective.

4. The tiles which determine the paths of the gases in water-tube boilers often get displaced or broken. This causes additional short circuiting of gases,

to which water-tube boilers are subject, thus rendering portions of the heating surface of little value. This cannot take place in horizontal tubular boilers. The distance from the bridge wall of the latter boiler to the top of the up-take is the same through any tube, and the resistance is the same. There is no reason, therefore, for short circuiting, and no other boiler is so ideal in this respect. The vertical fire-tube boiler is more economical than the horizontal, maintains its economy better on account of the absence of brickwork, and plants equipped with them will be found to be more economical than others.

5. Due to the defects mentioned above, the economy of water-tube boilers diminishes with age, while that of fire-tube boilers is, with good water, more constant. With poor water the economy can be restored by cracking the scale off the tubes, as already described.

At a certain plant where there were both Manning and water-tube boilers, the former, when operating the same engine, saved some 32 per cent. of coal over the latter in regular operation during periods of six months. Afterwards the water-tube boilers were put in order and were less wasteful. This brings out, strongly, the defects of water-tube boilers, and shows how they fall off in economy with age.

The relative economies of various types of boilers can be seen from an examination of the annexed tables, pages 16 to 19.

Life of Boilers and Reduction of Pressure.

The life of boilers, when built in the best manner, is not dependent upon the type. It is dependent upon what happens to the boilers. A fire-tube boiler, when built in this manner, has an indefinite life, and it may be thirty years or even more. There is no reason for reducing the pressure unless the boiler has been injured by dirt or corrosion, or defective material was used. There is nothing in the Massachusetts boiler rules that indicates that there is a probability of a reduction of pressure in any type after a certain length of service if it is built in accordance with those rules. Water-tube boilers have no longer life than fire tube, and from their complicated forms and uncertain strains should have less.

High Pressures.

The gradual tendency towards the use of higher steam pressures has caused a good deal of speculation as to the best type of boiler to stand them. Many horizontal return tubular boilers have been built to carry 160 to 185 pounds or more per square inch.

It has been thought by many persons that the thick plates necessary for high

pressures with this type are a source of danger on account of possible overheating. An examination of the theory of the transmission of heat through steel plates will show that their capacity to transmit heat is scarcely affected by any probable thickness that will be used. The resistance to the transmission of heat from a fire to the water in such a boiler is chiefly due to the soot on the outside of the plate and dirt on the inside. An accumulation of soot on the outside is a protection to the plate from overheating wherever there is dirt on the inside. Dirt on the inside causes bagging with thin plates and nothing more with thick ones.

In 1890 an important paper was read before the North East Coast Institution of Engineers and Shipbuilders in England, by W. Kilvington and Alexander Taylor, on the use of thick plates for the furnaces of marine boilers. It had been for many years considered that 3/8 inch was the greatest advisable thickness for such furnaces. This after a few years was increased to 1/2 inch, and in 1890 few engineers objected to furnaces 5/8 inch thick. About the same change in opinion on this subject has taken place in regard to the thickness of plates of horizontal return tubular boilers.

The writers of the paper referred to state that they know of no furnace that has collapsed from being too thick. Cases of collapse have always been due to oil and dirt accumulating on the furnace, and this is the only cause of a horizontal return tubular boiler bagging on the bottom. It is also the cause of explosions (see page 25) and bagging of the tubes of water-tube boilers. In 1890 there had been furnaces at sea for three or four years, 3/4 inch thick and subjected to 160 pounds pressure without failure. The writers of the paper have investigated the resistance offered by a 3/4-inch plate over a 5/8-inch plate, and find it only 1 per cent. They show that this was long ago known by Rankine, who wrote: " The external thermal resistance of the metal plates of boiler flues and tubes, and other apparatus used for heating and cooling fluids, is so much greater than the internal thermal resistance that the latter is inappreciable in comparison; and consequently the nature and thickness of those plates has no appreciable effect on the rate of conduction through them." Rankine also states that the results of evaporative tests of boilers justify the disregard of the effect of thickness on the rate of transfer of heat.

In 1867 Mr. Isherwood made some experiments on the transmission of heat through plates varying from 1/8 to 3/8 inch in thickness, a variation of 300 per cent., where one side was exposed to steam and the other side to water, and he states that the difference in thickness did not measurably influence the result.

Messrs. Kilvington and Taylor decided that they would not hesitate to use plates of marine furnaces 1 inch in thickness. They also concluded that the

same amount of scale and dirt will cause a thin plate to collapse as soon as a thick plate.

All of the above reasoning applies to horizontal tubular boilers, and the only inference to be drawn from it is that safety and efficiency are not to a measurable extent affected by an increase in the thickness of plates. Since 1880 thicknesses have increased from 3/8 inch to 3/4 inch, and the writer has had built 90-inch boilers with plates 23/32 inch thick to carry 165 pounds of steam, which have been in service more than ten years, and should not hesitate to use plates 15/16 inch or more in thickness. A 100-inch boiler for 200 pounds would require this thickness.

With plates as thick as 5/8 inch or more, where they lap and form the circular joints there is a double thickness which is considerable. This is easily overcome by planing down the plates where they lap, but many horizontal tubular boilers with 5/8-inch plates have been built without this refinement. This does not apply to the longitudinal joints, as they are above the fire surface. Planing the plates for the circular joints does not weaken boilers because these joints are strained but little. Any thickness that can be caulked is ample to stand the stress from pressure, and in general it can be said that such plates can be planed to a thickness of 7/16 or 3/8 inch. With this done no difficulty from thick plates will occur, and such boilers can be used for any pressure that is likely to be demanded for many years to come. I do not hesitate to state that horizontal and vertical fire-tube boilers are better adapted for the highest pressures than any other type. It may be even unnecessary to thin down the plates at the circular joints, but this is an advisable precaution.

Vertical fire-tube boilers are available for high pressures, and the inner firebox can be made of thin plates if the staybolts are properly spaced. Such boilers have been made for from 185 to 205 pounds, many for 200 pounds, and in size up to 500 horsepower, the latter being over 10 feet in diameter and to carry 165 pounds.

The form of butt joints now generally used is not the best possible because it has more strength inside of the shell than outside, has some rivets overhung and is one-sided. To overcome this the outside and inside covering plates should be of the same width and all rivets in double shear. The efficiency of these joints is usually 92 per cent., and while the one-sided joint can be made theoretically of this efficiency, in practice it probably does not reach it.

Locomotive Type Boilers.

Number.	Year.	Location.	Grate Area (Square Feet).	Heating Surface (Square Feet).	Steam Pressure (Pounds).	Boiler Horse Power developed.	Kind of Coal.	Coal burned per Square Foot of Grate per Hour (Pounds).	Water evaporated per Hour per Square Foot Heating Surface from and at 212° (Pounds).	Evaporation from and at 212°.		Boiler Horse Power per Square Foot of Grate.	Number Square Feet of Heating Surface per Horse Power.	Temperature Escaping Gases (Degrees F.).	Tested by —	How fired.
										Per pound Coal (Pounds).	Per pound Combustible (Pounds).					
1	1893	New Bedford Water Works,	30.50	1,883	114	94.55	Cumberland.	8.85	1.49	12.08	12.88	3.10	19.92	360	Dean.	Hand.
2	1893	New Bedford Water Works,	30.50	1,883	113	173.84	Cumberland.	16.06	2.72	12.23	12.90	5.70	10.83	469	Dean.	Hand.
3	1893	New Bedford Water Works,	45.00	1,883	113	92.75	Pocahontas.	6.31	1.70	11.29	12.10	2.06	20.30	384	Dean.	Hand.
4	1893	New Bedford Water Works,	45.00	1,883	113	176.66	Pocahontas.	12.18	3.24	11.12	11.93	3.93	10.65	538	Dean.	Hand.
5	1892	Newton Water Works,	48.12	2,310	126	114.20	Cumberland.	7.23	1.51	11.32	12.24	2.37	20.20	440	Dean.	Hand.
6	1894	Taunton Locomotive Company,	27.25	1,412	95	70.70	Cumberland.	8.22	1.73	10.89	11.83	2.60	19.97	401	Dean.	Hand.
7	1897	Boston Water Works,	20.62	937	78	38.00	Cumberland.	5.95	1.40	10.71	12.09	–	24.70	–	Dean.	Hand.
8	1885	Boston Sewage Works,	45.50	1,826	–	112.00	Cumberland.	7.35	–	11.60	12.23	–	–	–	Brackett.	Hand.
9	1885	Boston Sewage Works,	45.50	1,826	–	129.00	Cumberland.	8.62	–	11.35	11.98	–	–	439	Brackett.	Hand.
10	1892	Mason Machine Works,	30.30	976	85	–	Cumberland.	4.66	1.52	10.53	11.66	–	–	365	Dean.	Hand.
11	1898	Lynn Water Works,	29.00	1,500	89	136.00	Cumberland.	14.00	3.13	11.53	12.84	4.69	11.03	420	Dean.	Hand.
12	1898	Lynn Water Works,	29.00	1,500	89	150.00	Cumberland.	16.00	3.44	11.08	12.04	5.17	10.00	478	Dean.	Hand.
13	1897	Washington Mills,[1]	60.00	5,300	122	623.00	Pocahontas.	31.66	4.05	11.32	12.47	10.38	8.51	526	Dean.	Hand.
14	1897	Washington Mills,[1]	60.00	5,300	123	581.00	New River.	28.10	3.78	11.87	12.96	9.69	9.12	516	Dean.	Hand.
15	1897	Washington Mills,[1]	60.00	5,300	123	557.00	New River.	28.50	3.63	11.25	12.33	9.29	9.50	496	Dean.	Hand.
16	1897	Washington Mills,[1]	60.00	5,300	123	572.00	Pocahontas.	29.30	3.72	11.24	12.48	9.54	9.26	511	Dean.	Hand.
17	1898	Washington Mills,[1]	60.00	5,300	119	416.00	New River.	21.30	2.71	11.22	12.31	6.94	12.72	472	Dean.	Hand.
18	1898	Washington Mills,[1]	60.00	5,300	123	426.00	Pocahontas.	20.90	2.71	11.73	12.93	7.10	12.42	482	Dean.	Hand.
19	1891	Old Colony Locomotive on fast freight.	19.00	1,400	174[2]	–	Pocahontas and Cumberland.	58.00 to 68.00	–	9.68 to 10.74	10.58 to 11.93	–	–	–	–	–
20	1892	Oxford, Eng., Electric Light Station.	–	–	–	–	–	–	–	11.75	–	–	–	–	Unwin (?).	Hand.
21	1887	3 tests, Great Eastern Railway, England.	12.40	859	124[2]	–	Nixon's Navigation.	28.10 to 35.50	5.10 to 6.25	12.18 to 12.51	13.00 to 13.30	–	–	570 to 617	Donkin and Kennedy.	Hand.
22	1887	Rankin's Factory, London,	9.68	316	61	–	Nixon's Navigation.	12.40	4.05	10.78	11.25	–	–	625	Donkin and Kennedy.	Hand.
23	1889	Brussels, Belgium,	31.43	1,177	90	–	Nixon's Navigation.	25.50	7.23	10.64	11.42	–	–	–	Donkin and Kennedy.	Hand.
24	1879	Lawrence Water Works,	28.75	1,020	90	–	Cumberland.	8.38	2.71	11.49	12.24	–	–	–	R. H. Buel.	Hand.

[1] These boilers have corrugated furnaces instead of staybolt furnaces.

[2] Average.

Horizontal Return Tubular Boilers.

Number.	Year.	Location.	Grate Area (Square Feet).	Heating Surface (Square Feet).	Steam Pressure (Pounds).	Boiler Horse Power developed.	Kind of Coal.	Coal burned per Square Foot of Grate per Hour (Pounds).	Water evaporated per Hour per Square Foot Heating Surface from and at 212° (Pounds).	Evaporation from and at 212°. Coal per pound (Pounds).	Evaporation from and at 212°. Per Pound Combustible (Pounds).	Boiler Horse Power per Square Foot of Grate.	Number Square Feet of Heating Surface per Horse Power.	Temperature Escaping Gases (Degrees F.).	Tested by —	How fired.
25	1890	Washington Mills,	56.00	2,240	133	–	Cumberland.	9.52	2.09	10.62	11.21	–	–	428	Leavitt.	Hand.
26	1894	Boston Water Works,	36.75	2,164	67	167	Pocahontas.	13.42	2.66	11.42	12.23	4.54	12.96	389	Dean.	Hand.
27	1894	Atlantic Mills,[1]	21.77	1,112	84	139	Cumberland.	21.40	4.30	10.46	11.18	6.37	8.00	373	Dean.	Hand.
28	1894	Atlantic Mills,[1]	21.51	1,112	85	145	Cumberland.	21.70	4.49	10.71	11.57	6.73	7.70	389	Dean.	Hand.
29	1895	Laurel Lake Mills,	36.00	1,787	107	91	Clinch Valley.	8.25	1.75	10.52	11.84	2.52	19.71	350	Dean.	Hand.
30	1900	Cumberland Mills,[2]	48.75	4,027	92	630	Cumberland.	42.20	5.39	10.57	11.53	12.92	6.39	569	Dean.	Hand.
31	1900	Cumberland Mills,[2]	61.87	4,027	94	742	Cumberland.	37.60	6.35	11.53	12.06	12.00	5.43	645	Dean.	Chain grate stoker.
32	1900	Cumberland Mills,[2]	48.75	4,027	96	353	Cumberland.	22.50	3.02	11.11	12.84	7.42	11.41	473	Dean.	Hand.
33	1900	Cumberland Mills,[2]	61.87	4,027	95	383	Cumberland.	21.30	3.28	11.41	13.27	6.19	10.53	492	Dean.	Chain grate stoker.
34	1896	Globe Yarn Mills,	25.00	1,400	115	132	Pocahontas.	17.80	3.27	10.28	11.02	5.28	10.60	388	Dean.	Hand.
35	1894	Lowell Water Works,	36.00	1,755	148	106	Cumberland.	10.11	2.09	10.08	11.00	2.95	16.56	372	Dean.	Hand.
36	Unk.	3 boilers,	90.00	3,374	84	204	Cumberland.	7.00	1.80	11.33	12.07	–	–	431	Barrus.	Hand.
37	Unk.	2 boilers,	49.30	2,100	65	178	Cumberland.	11.10	2.60	11.20	11.98	–	–	408	Barrus.	Hand.
38	1902[3]	Bigelow Carpet Company,	49.00	2,600	34	273	Eureka.	17.00	3.60	11.80	12.70	5.57	9.52	448	Hale.	Hand.
39	1897	– –	36.00	1,426	36	200	Pocahontas.	16.80	4.20	11.37	12.14	5.55	7.13	593	Barrus.	Hand.
40	1897	– –	31.50	1,426	58	168	Pocahontas.	16.40	3.55	11.26	12.01	5.33	8.48	594	Barrus.	Hand.
41	1906[4]	Palmer Mill,	264.00	13,496	124	989	Pardee.	11.62	2.09	10.03	12.08	3.74	13.64	457	Allen-Perkins.	Hand.
42	1905[5]	– –	67.50	2,834	116	228	Pocahontas.	10.90	2.78	10.80	11.90	3.37	12.42	443	Green.	Hand.
43	1904[2]	Arnold Print Works,	48.75	3,020	80	312	Eclipse.	21.00	3.57	10.67	12.55	6.40	9.67	398	Pead.	Jones Stoker.
44	1904[2]	Arnold Print Works,	34.00	1,500	77	146	Mexican Bituminous and Buckwheat.	15.90	3.52	9.87	12.75	4.29	10.27	333	Pead.	Hand.
45	1908[2]	St. Croix Paper Company,	79.00	3,820	107	479	Pardee.	18.45	4.32	11.30	12.32	6.06	7.97	585	Farwell.	Murphy stoker.
46	1908[2]	St. Croix Paper Company,	79.00	3,820	116	396	Pardee.	15.00	3.58	11.77	12.84	5.01	9.64	540	Farwell.	Murphy stoker.

[1] This boiler was 24 years old when tested and had the original set of tubes.

[2] These tests made on boilers 90″ diam.

[3] This test made on boiler 84″ diam., with 3″ tubes, 19 ft. long.

[4] Battery of eight boilers.

[5] Battery of two boilers.

Vertical Water-leg Boilers.

Number.	Year.	Location.	Grate Area (Square Feet).	Water-heating Surface and Total Square Feet.	Steam Pressure (Pounds).	Boiler Horse Power developed.	Kind of Coal.	Coal burned per Square Foot of Grate per Hour (Pounds).	Water evaporated per Hour per Square Foot Heating Surface from and at 212° (Pounds).	Evaporation from and at 212°. Per pound Coal (Pounds).	Evaporation from and at 212°. Per pound Combustible (Pounds).	Boiler Horse Power per Square Foot of Grate.	Number Square Feet of Heating Surface per Horse Power.	Temperature Escaping Gases (Degrees F.).	Tested by —	How fired.
47	Unk.	– – –	28.30	1,260 1,700	46	243	Cumberland.	13.10	3.20[1]	11.34	12.29	–	–	427	Barrus.	Hand.
48	1897	Grosvenordale Mills, . . .	33.20	1,489 2,154	153	123	Cumberland.	11.70	2.86[1]	10.94	11.96	3.72	12.00[1]	520	Barrus.	Hand.
49	1894	Whitman Mills, ...	28.27	1,388 1,869	123	194	Pocahontas.	23.00	4.90[1]	10.07	12.00	6.85	7.00[1]	531	Denton.	Hand.
50	1894	Whitman Mills, ...	28.27	1,388 1,869	123	126	Pocahontas.	14.70	3.10[1]	10.38	12.32	4.47	11.00[1]	496	Denton.	Hand.
51	1894	Whitman Mills, ...	28.27	1,388 1,869	156	95	Pocahontas.	10.90	2.30[1]	10.62	12.35	3.38	15.00[1]	362	Denton.	Hand.
52	1894	Manchester Water Works, . .	28.27	1,388 1,869	142	98	Cumberland.	11.00	2.44[1]	10.89	11.92	3.47	14.00[1]	380	Dean.	Hand.
53	1894	Manchester Water Works, . .	28.27	1,388 1,869	140	103	Cumberland.	12.64	2.56[1]	9.92	11.11	3.64	13.30[1]	397	Dean.	Hand.
54	1894	Narragansett Mills, . . .	33.40	1,384 2,036	114	119	Pocahontas.	11.30	2.90[1]	11.19	11.92	3.57	11.60[1]	395	Dean.	Hand.
55	1894	Narragansett Mills, . . .	33.40	1,492 2,036	115	162	Pocahontas.	15.20	3.69[1]	10.02	11.83	4.85	9.20[1]	439	Dean.	Hand.
56	1894	Kunhardt's Mill, ...	28.20	[2] 1,745	67	115	Cumberland.	12.70	2.28[3]	10.96	11.64	4.09	15.10[3]	491	Dean.	Hand.
57	1894	Kunhardt's Mill, ...	28.20	[2] 1,745	69	102	Cumberland.	11.50	2.02[3]	10.82	11.48	3.62	17.10[3]	519	Dean.	Hand.
58	1895	Berkeley Mill, ...	33.40	1,384 2,037	129	103	Pocahontas.	10.37	2.57[1]	10.25	11.12	3.09	13.40[1]	437	Dean.	Hand.
59	1895	Fletcher Manufacturing Company,	33.40	1,897 2,431	79	226	Pocahontas.	21.56	4.11[1]	10.83	11.50	6.77	8.40[1]	422	Dean.	Hand.
60	1895	Fletcher Manufacturing Company,	33.40	1,897 2,431	79	177	Cumberland.	17.63	3.21[1]	10.35	11.11	5.30	10.70[1]	414	Dean.	Hand.
61	1910	Cumberland Mills, . . .	76.50	4,900 6,081	123	757	New River.	30.50	5.33[1]	11.20	12.77	9.90	6.46[1]	561	Chase.	Chain grate stoker.
62	1910	Cumberland Mills, . . .	76.50	4,900 6,081	116	830	New River.	33.40	5.85[1]	11.22	12.62	10.85	5.90[1]	573	Chase.	Chain grate stoker.
63	1898	– – –	28.27	1,347 1,796	160	110	Pocahontas.	11.20	2.42	12.09	12.76	3.88	12.24	418	Manning.	Hand.
64	1900	– – –	52.00	2,498 3,393	107	350	Cumberland.	20.80	4.84	11.17	12.37	6.73	7.13	742	Manning.	Roney stoker.
65	1897	– – –	28.30	1,260 1,700	99	132	Pocahontas.	13.60	3.10	11.89	12.74	4.66	9.54	522	Barrus.	Hand.
66	1901	– – –	38.50	2,174 2,852	115	192	Cumberland.	15.89	3.04	10.57	12.47	4.98	11.32	368	Green.	Hand.
67	1894	Bristol Manufacturing Corporation.	169.62	8,298 11,124	125	747	Pocahontas.	13.71	3.19	10.80	13.09	4.40	11.10	510	Denton.	Hand.
68	1894	Bristol Manufacturing Corporation.	226.16	11,064 14,832	124	797	Pocahontas.	10.42	2.48	11.09	13.41	3.52	13.88	467	Denton.	Hand.
69	1894	Bristol Manufacturing Corporation.	197.89	9,681 12,978	125	715	Pocahontas.	11.01	2.55	10.75	13.02	3.61	13.53	460	Denton.	Hand.

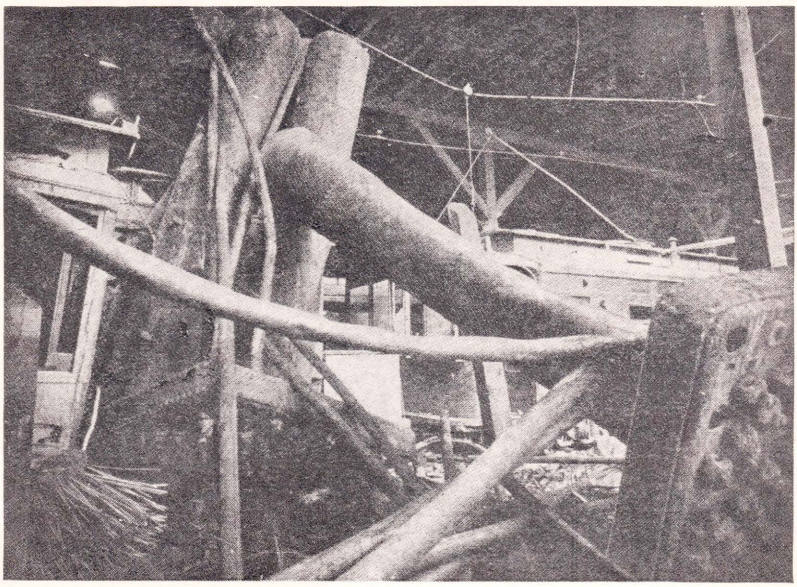
[1] Excluding superheating surface. [2] Total. [3] Including superheating surface.

Horizontal Water Tube Boilers.

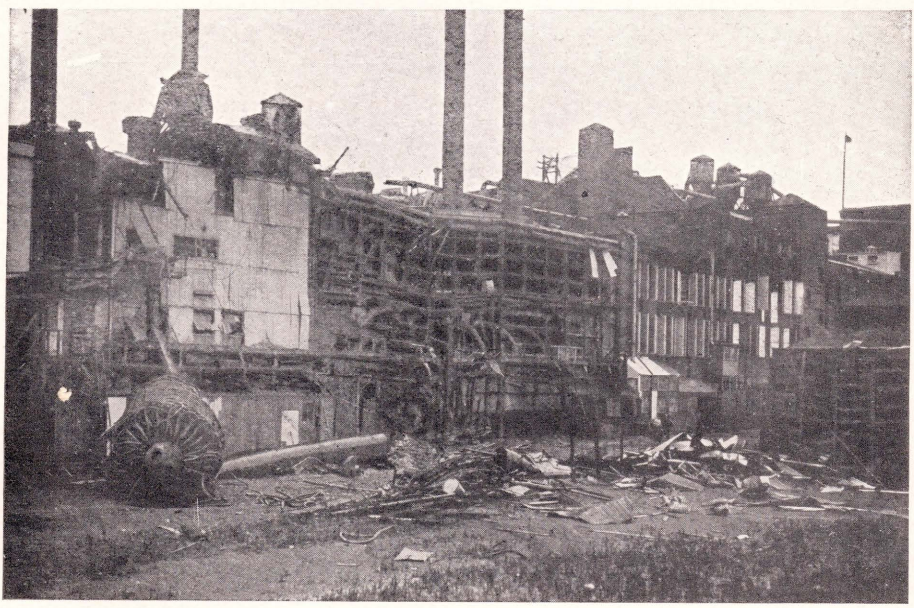
Number.	Year.	Location.	Grate Area (Square Feet).	Heating Surface (Square Feet).	Steam Pressure (Pounds).	Boiler Horse Power developed.	Kind of Coal.	Coal burned per Square Foot of Grate per Hour (Pounds).	Water evaporated per Hour per Square Foot Heating Surface from and at 212° (Pounds).	Evaporation from and at 212°.		Boiler Horse Power per Square Foot of Grate.	Number Square Feet of Heating Surface per Horse Power.	Temperature Escaping Gases (Degrees F.).	Tested by —	How fired.
										Per pound Coal (Pounds).	Per Pound Combustible (Pounds).					
70	1894	Natick Mills,	70.00	3,467	150	252	Cumberland.	12.57	2.50	9.88	10.51	3.60	13.76	416	Dean.	Hand.
71	1894	Natick Mills,	70.00	3,467	140	231	Cumberland.	11.03	2.29	9.52	10.24	3.30	15.00	388	Dean.	Hand.
72	1895	Cumberland Mills,	59.50	2,649	82	409	Pocahontas.	24.34	5.32	9.74	10.53	6.88	6.48	553	Dean.	Hand.
73	1895	Cumberland Mills,	42.25	2,649	74	297	Pocahontas.	22.34	3.87	10.86	11.91	7.03	8.91	361	Dean.	Chain grate stoker.
74	1835	Cumberland Mills,	42.25	2,649	76	322	Pocahontas.	25.54	4.19	10.30	11.49	7.58	8.22	372	Dean.	Chain grate stoker.
75	1895	Cumberland Mills,	42.25	2,649	–	–	Cumberland.	23.90	4.36	11.01	12.19	–	–	388	Whitham.	Chain grate stoker.
76	1897	Providence Worsted Company,	26.00	1,390	89	166	Reynoldsville.	26.00	4.12	8.47	9.33	6.38	8.38	473	Dean.	Hand.
77	1897	Providence Worsted Company,	26.00	1,390	92	173	Reynoldsville.	26.60	4.29	8.61	9.23	6.65	8.05	504	Dean.	Hand.
78	–	James Row, Troy, N. Y.,	–	–	–	183	Cumberland.	14.53	5.38	9.83	–	–	5.77	–	Barrus.	Hand.
79	–	Warren Manufacturing Company,	–	–	–	132	Cumberland.	30.70	4.75	10.25	–	–	7.26	–	Evans.	Hand.
80	1886	Cocheco Mills,	–	–	–	–	Cumberland.	16.32	3.45	10.27	10.98	–	–	428	Barrus.	Hand.
81	1896	Tremont and Suffolk Mills,	–	–	–	–	–	23.11	4.06	10.94	11.83	–	–	470	Peabody.	Chain grate stoker.
82	Unk.	–	–	–	67	243	Cumberland.	16.80	2.30	9.95	10.79	–	–	452	Barrus.	Hand.
83	Unk.	–	38.90	1,886	–	–	–	16.30	2.90	10.28	10.98	–	–	–	Barrus.	Hand.

Explosion of water-tube boilers at the plant of the Pabst Brewing Company, Milwaukee, Wis., Oct. 25, 1909. Number killed, 1; number injured, 5; property loss, $114,000.

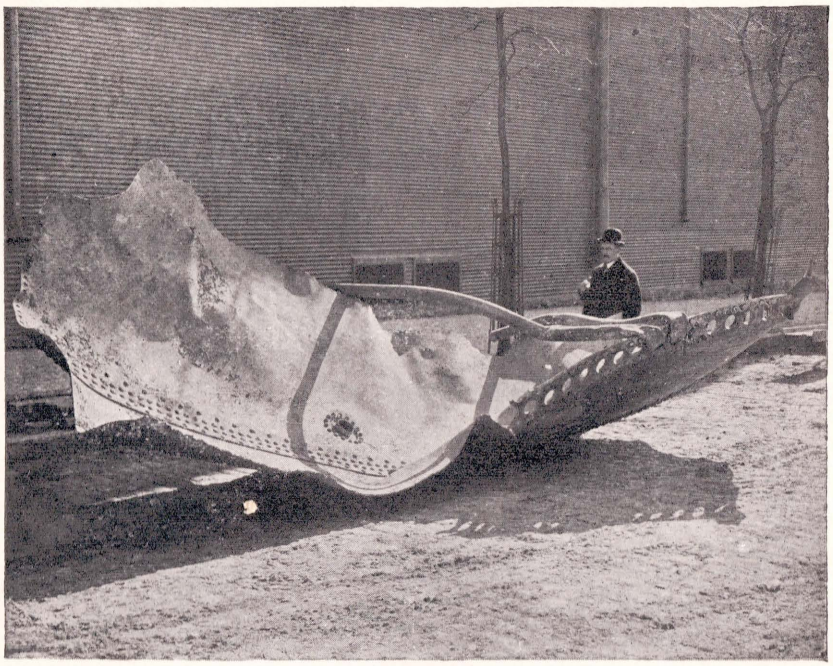
The morning after a water-tube boiler explosion.



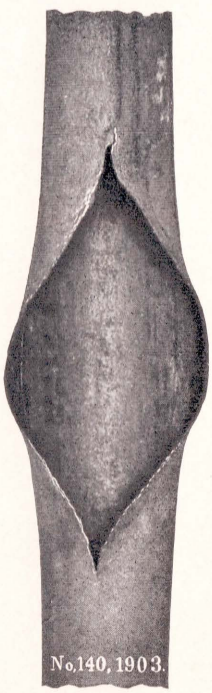
View of explosion of seven water-tube boilers at the plant of the St. Louis Transit Company, 1903. Number killed, 8; number injured, 21; property loss, $125,000.



Explosion of a 600-horse power water-tube boiler at the plant of the American Manufacturing Company, Brooklyn, N. Y., Oct. 20, 1910. Number killed, 7; number injured, 12; property loss, $150,000.



A ruptured drum of a water-tube boiler.



Ruptured tube from a
water-tube boiler.